Accelerated Anaerobic Bioremediation for Groundwater

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Overview

- Microbiology primer & contaminants amenable to anaerobic bioremediation
- Electron donors (i.e., substrate)
- Pertinent aquifer characteristics & alternatives for delivering electron donors to the contaminated zone

Microbiology Primer

- Breath air + eat food ---> get energy

- Air (electron acceptor)
- Food (electron donor)
  - Traditionally, the electron donor is the contaminant

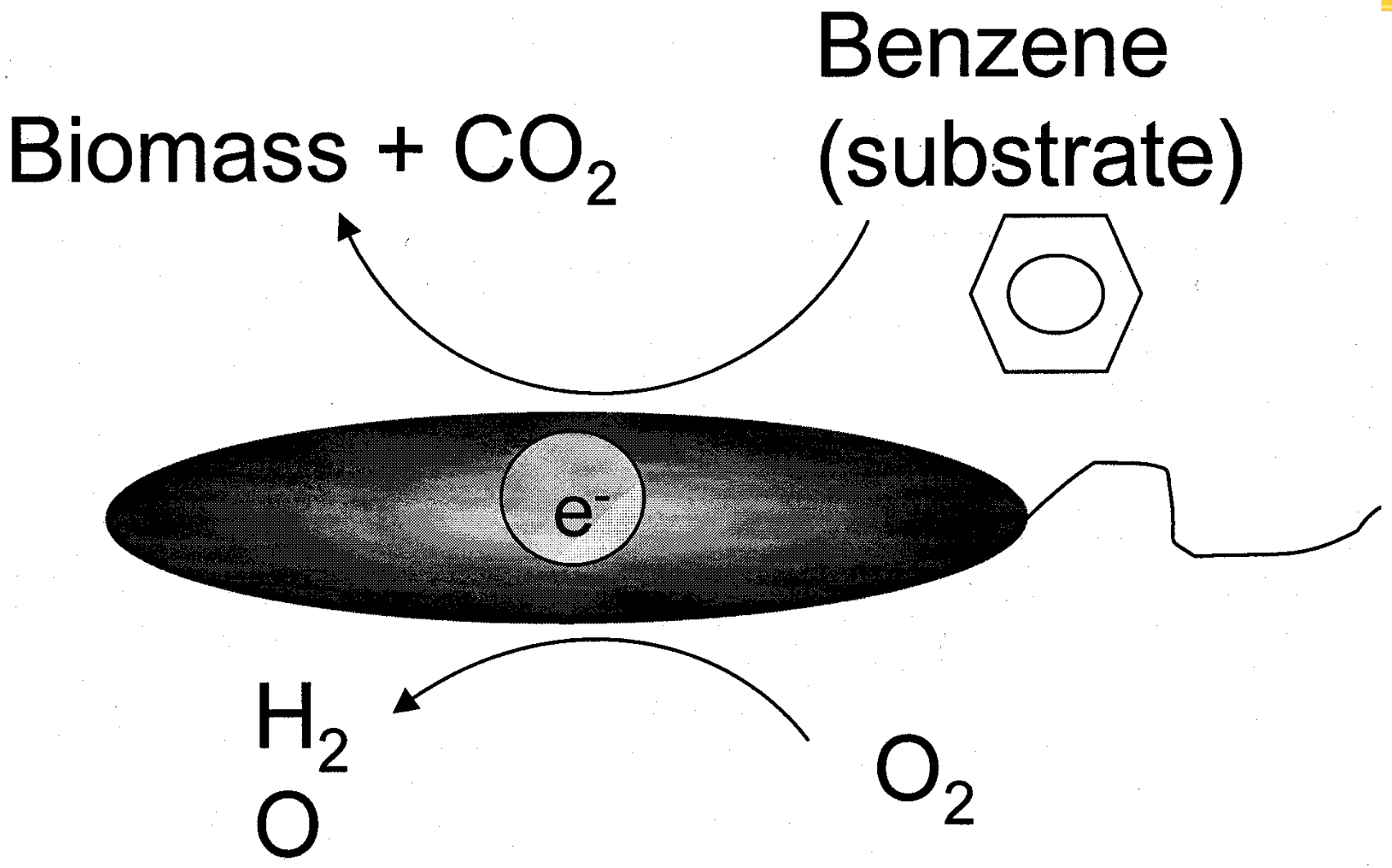
Electron Acceptors

- Oxygen
- Nitrate
- Iron III
- Sulfate
- Carbon Dioxide

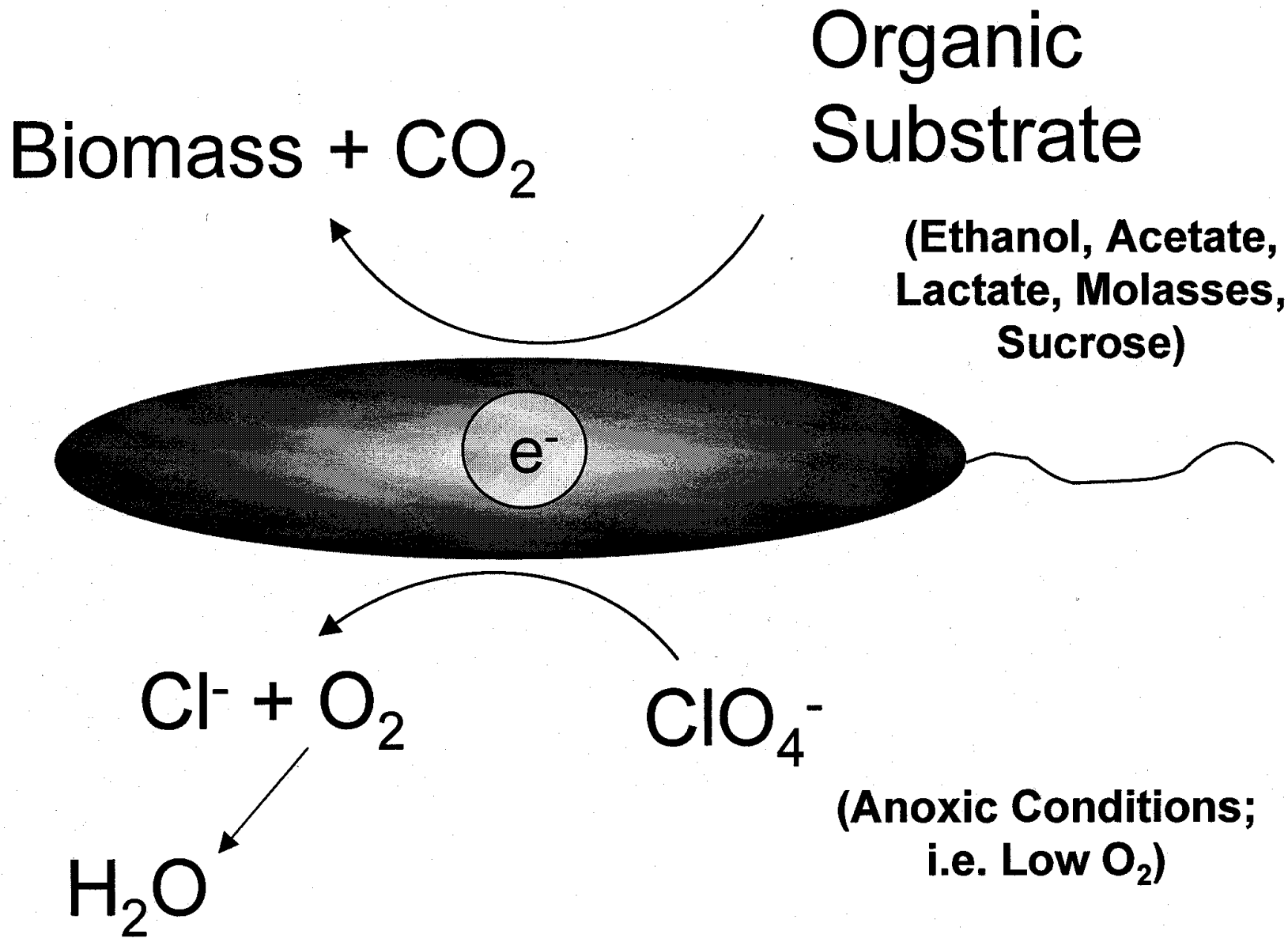
Electron Acceptors

- Oxygen
- Nitrate / Perchlorate
- Iron III
- Chromium VI
- Sulfate / Chlorinated Solvents
- Carbon Dioxide

Microbiology Primer



Microbiology Primer



Microbiology Primer

Electron Acceptor		Electron Donor		
nitrate, or sulfate, or TCE	+	lactate, or edible oil, or molasses	→	"drives" microbe (i.e., microbe obtains energy)

Contaminants Amenable to Accelerated Anaerobic Bioremediation

- Nitrate
- Perchlorate
- Chromium VI
- Some Explosives (RDX, TNT, HMX)
- Chlorinated solvents / DNAPL

Contaminants Amenable

- DNAPL bioremediation
  - 5-fold increase in rate of DNAPL (PCE) dissolution observed in lab during dehalorespiration
- Dehalogenation not inhibited at concentrations up to:
  - PCE 148 mg/L
  - TCE 297 mg/L
  - DCE 64 mg/L
- Rates of dehalogenation highest when dissolved-phase PCE concentration is near maximum

Categories of Electron Donors

- Gases
- Water soluble liquids
- Slow-release liquids & solids
  - Synthetic organic polymers (i.e., HRC)
  - Oils & oil / water emulsions
  - Solid organic materials

Soybean Oil - Properties

- Specific Gravity = 0.92
- Solidification Point = 3.2 to 14 degrees F
- Relatively low viscosity
  - Usually can be injected at relatively low pressure

Soybean Oil – Additional Considerations

- Oil / water emulsions vs. straight oil
  - Typically about 10% oil
  - Increased radial spread using emulsion (up to 24 ft from injection point), and wider distribution of electron donor

- Containment or biodegradation?
  - Some contaminants will partition into oil-phase
  - Rapid, initial decrease in TCE due to partitioning usually observed
  - Production of DCE, VC & ethene observed in lab

VICTOR

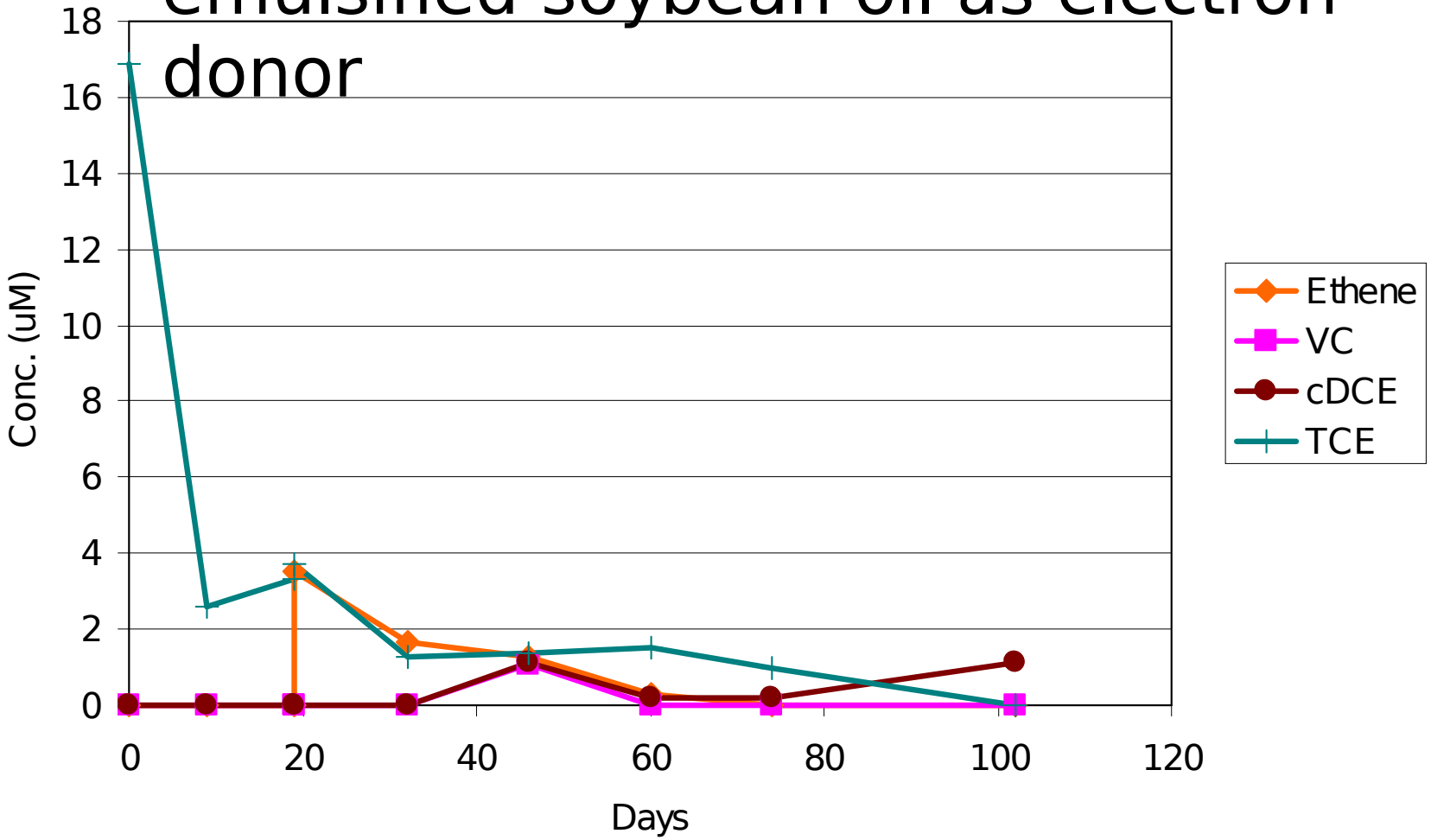
KOFLO
STATIC IN-LINE MIXER
JOB NO.
MODEL NO.
P.O. NO.
K-18745
I-SO-4-6-2

Microcosm Study Data

Atlas 10 Site, Nebraska

C Emulsified Oil +PDE

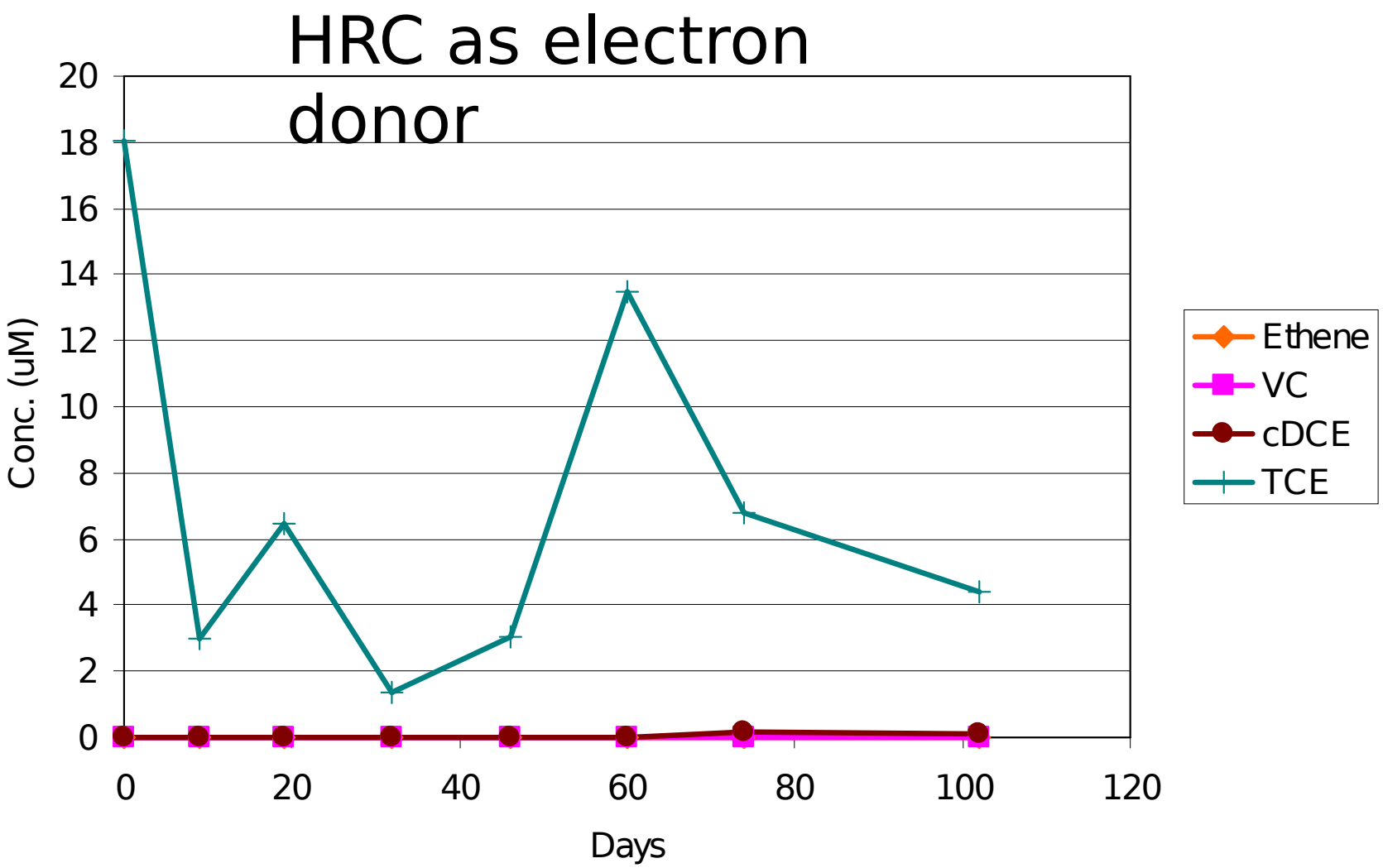
emulsified soybean oil as electron donor



Microcosm Study Data

Atlas 10 Site, Nebraska

A HRC



Relative Costs of Various Electron Donors

	$ per ton	$ per ton COD
whey	40	40
molasses	58	40-97
milk	50	40
lactic acid	1885	1765
soybean oil	700	350 (estimate)
HRC	16000	?
corn cobs	175	148
wood chips	25	20
newsprint	17.5	21

•Adapted from: Wu, W.-M. 1998. Anaerobic Dechlorination of Trichloroethylene (TCE) to Ethylene Using Complex Organic Materials. Wat. Res. 32:3591-3597. And DiStefano, T.D. 2000. PCE Dechlorination with Complex Electron Donors, in Bioremediation and Phytoremediation of Chlorinated and Recalcitrant Compounds, from The Second International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA, May 2000.

Comparative Efficiency of Electron Donors

- Efficiency – fraction of electron donor supplied that was used to degrade the contaminant of concern
- Rapidly fermented substrates (e.g., benzoate) may stimulate growth of methangenic bacteria, and inhibit growth of dechlorinating bacteria
- Optimum hydrogen range for dechlorination:
  - 2-11 nM (Yang & McCarty, 1998)

Aquifer Characteristics

- Geochemistry / Hydrogeology
  - Concentrations of competing electron acceptors: electron donor requirements should be estimated based on upgradient levels of dissolved oxygen, nitrate, iron III, & sulfate
  - High groundwater velocity aquifers (e.g., 1 ft/day) usually will require large quantities of electron donor to maintain anaerobic conditions

Aquifer Characteristics

- Beware of Agricultural Areas!
  - Electron donor demand due to:
  - 1) nitrate fertilizers, also
  - 2) irrigation may drive infiltration of dissolved oxygen and nitrate into the aquifer
  - Seasonal variation in groundwater direction and/or velocity due to operation of irrigation wells

Aquifer Characteristics
Potential Risks of Anaerobic Bioremediation

- Hydrogen sulfide generation if sulfate levels are substantial
  - Potentially toxic
  - Odor!
- Mobilization of some metals may occur
  - Iron II & Manganese
  - Arsenic – measure background levels

Aquifer Characteristics

- For in-situ treatment, success requires ***synergy*** between design & hydrogeology
- Direction of groundwater flow
  - Seasonal variation?
- Strategraphy
  - Isotrophic, or
  - Degree of anisotropy

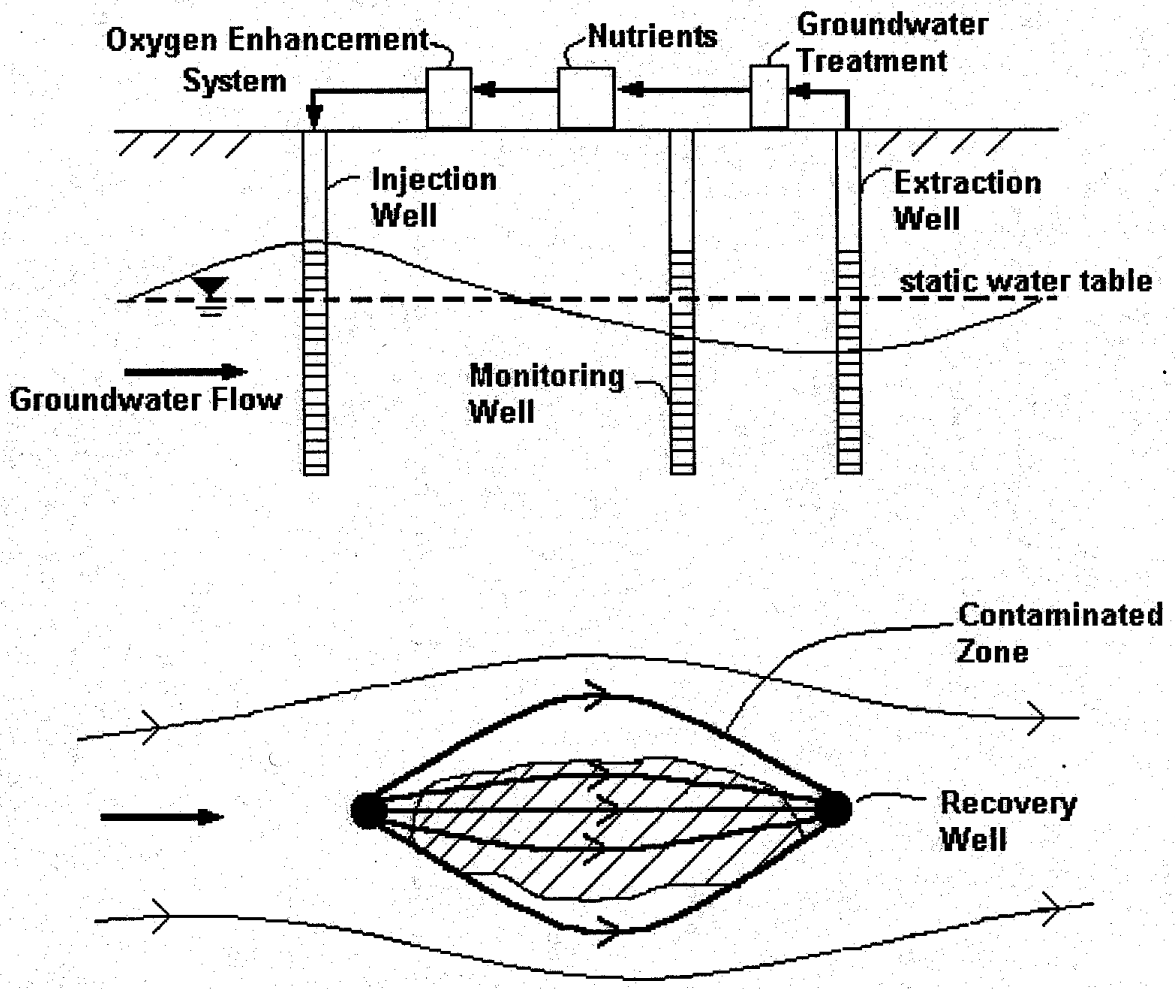
In-Situ Treatment: Systems & Configurations

- Continuous Circulation Systems
  - Continuous extraction / re-injection
- Semi-Passive Circulation Systems
  - Periodic substrate injection & groundwater circulation
- Passive Systems

Continuous Circulation Systems

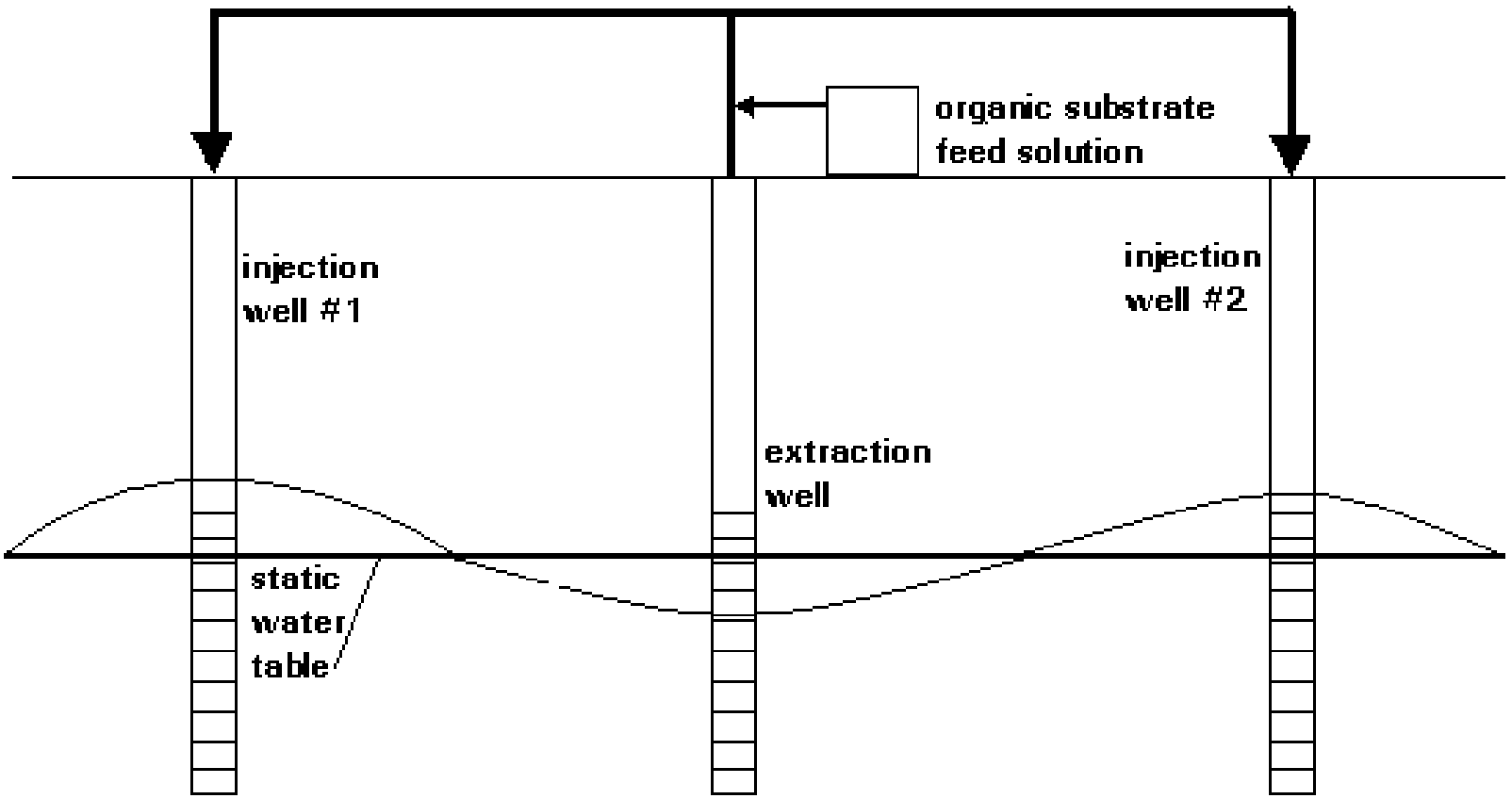
Extraction & Re-injection

Figure 1: Description of the Raymond Process

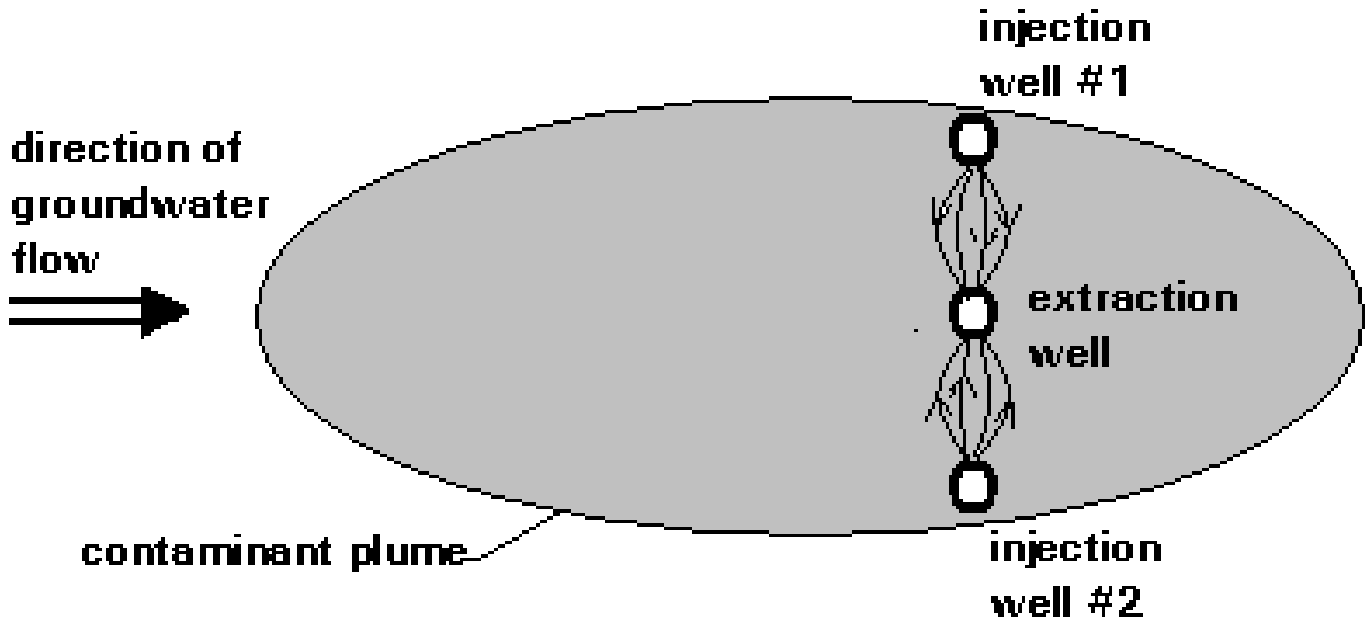


Source: Sutherson, Suthan S. *Remediation Engineering: Design Concepts*

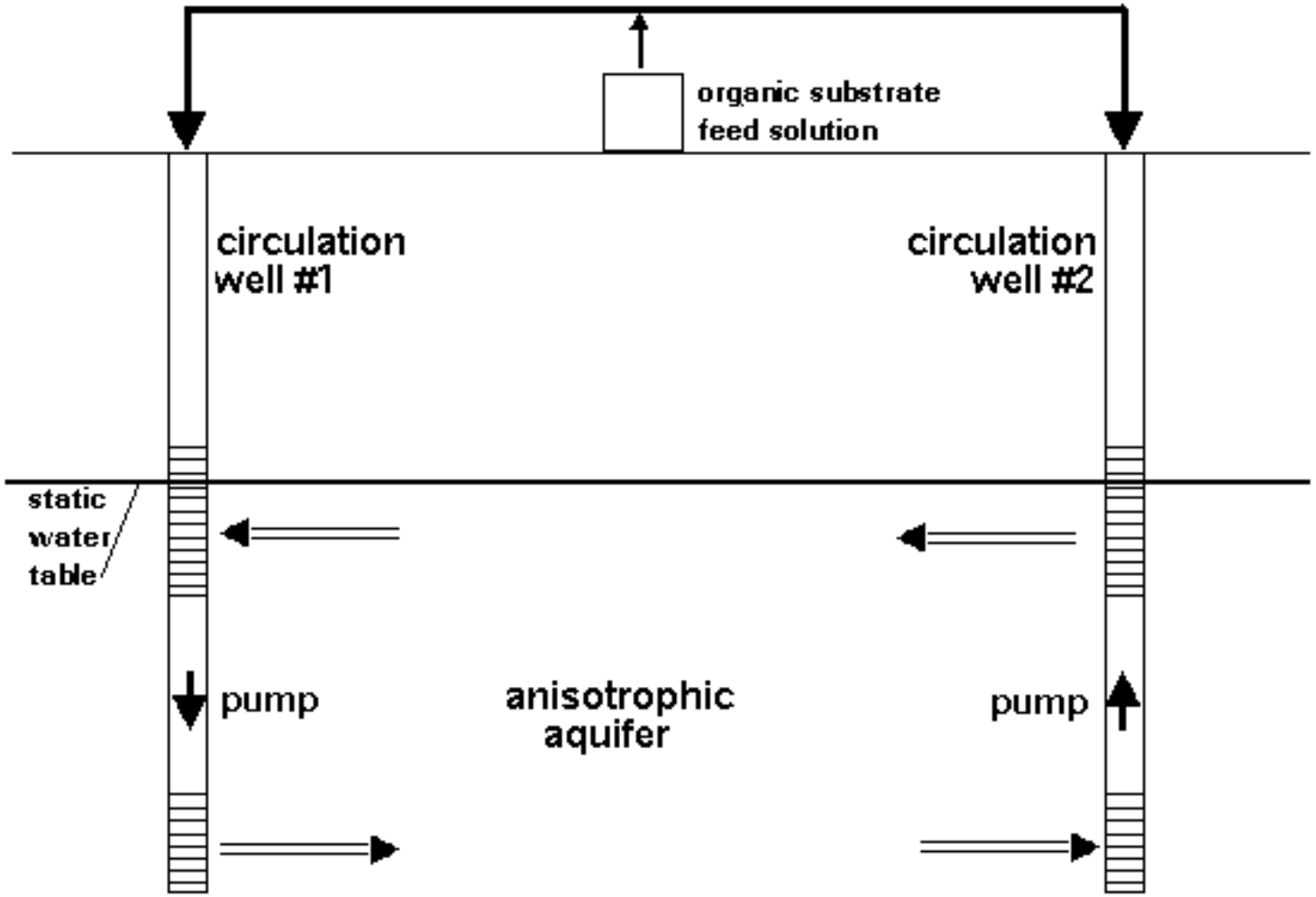
Semi-Passive Circulation System
Using Extraction & Re-injection



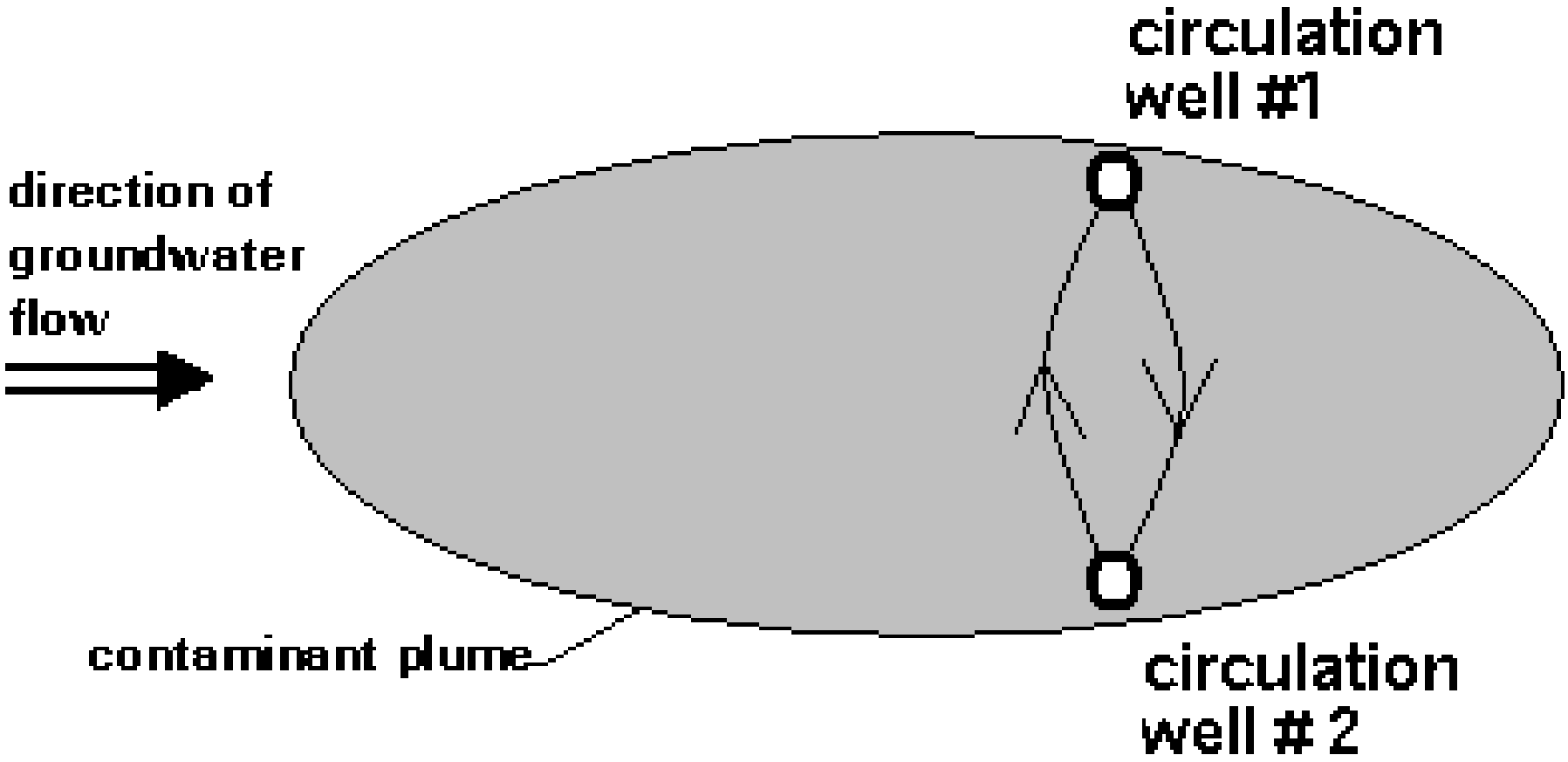
Semi-Passive Circulation System



Semi-Passive Circulation System
Without Groundwater Extraction



Semi-Passive Circulation System
Without Groundwater Extraction



In-Situ Treatment: Systems & Configurations

- Passive Systems
  - Substrate incorporated into permeable reactive barrier
  - Injection Point Barrier using Slow-release substrate
  - Periodic injection of soluble substrate

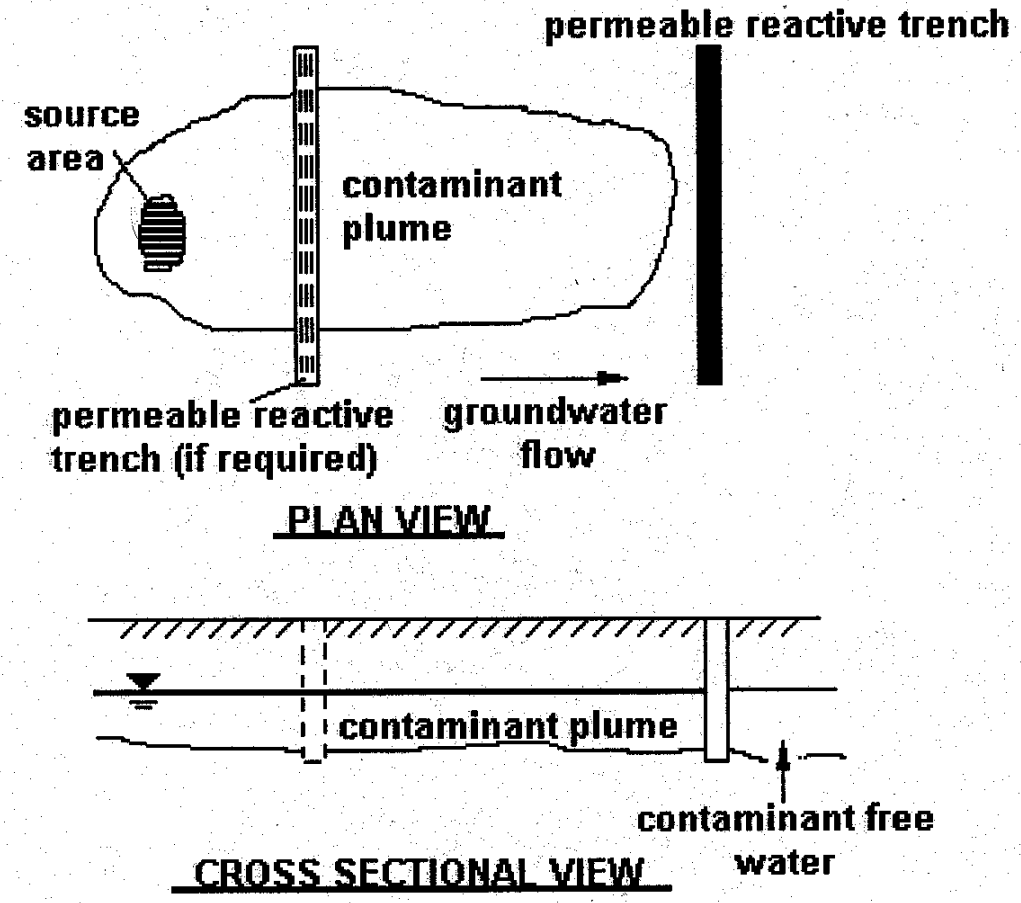
In-Situ Treatment

- Passive Systems
  - Advantages – minimal O&M requirements
  - Limitations – little or no control over mixing of contaminants & amendments

Passive Systems

Permeable Reactive Barrier

Figure 3: Plan and cross-sectional view of a permeable reactive trench



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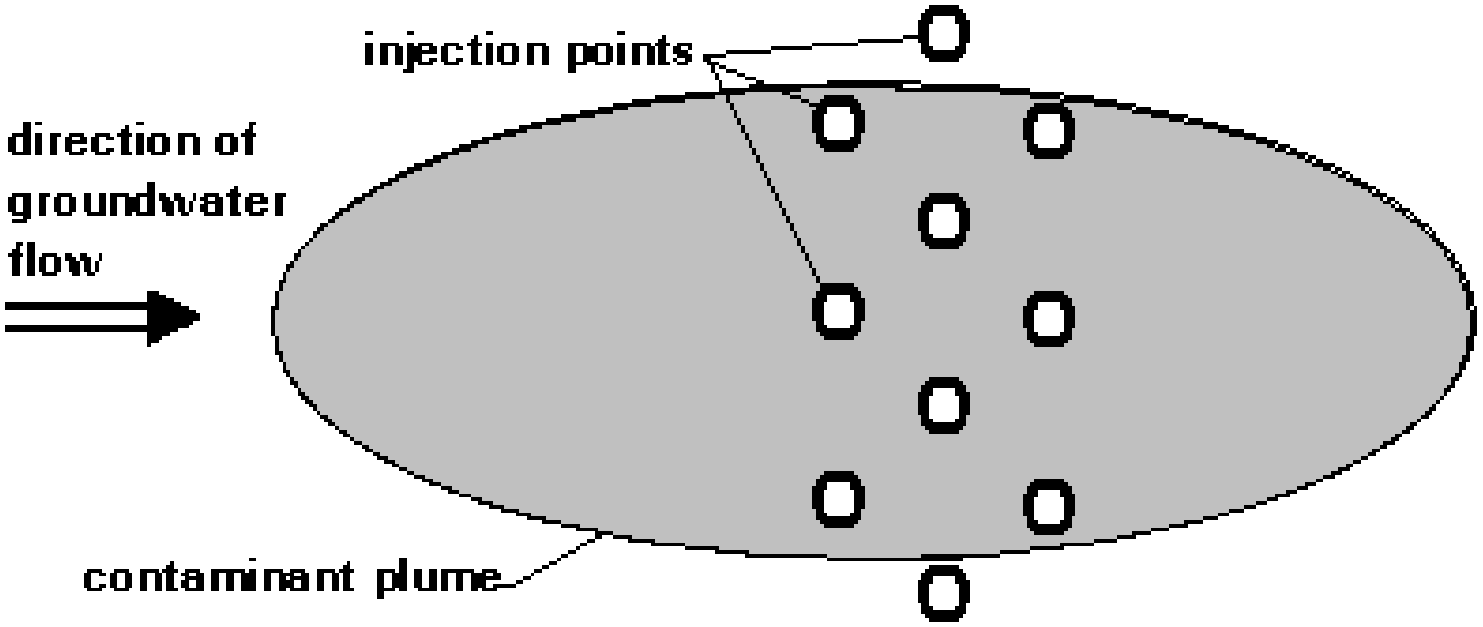
Passive Systems

Injection Point Barrier



Conclusions

- Principles of anaerobic bioremediation are the same for nitrate, perchlorate, Cr VI & chlorinated solvents
- Amenable contaminants also include: some explosives, & DNAPL (indirectly)
- COD content, cost, & microcosm-study data should be factored into electron donor selection

Conclusions (continued)

- Aquifer characteristics should be evaluated to determine feasibility of anaerobic bioremediation
- Pilot-scale field demonstrations should always precede full-scale implementation of in-situ bioremediation